Terra Validation Progress Report

Study: EOS Validation of Aerosol and Water Vapor Profiles by Raman Lidar
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Abstract

We are developing and using the aerosol extinction and backscattering profiles measured by two Raman lidar systems to validate the aerosol climatology models used by two Terra sensors, MODIS and MISR. The aerosol retrieval algorithms used by these EOS sensors operate by comparing measured radiances with tabulated radiances that have been computed for specific aerosol models. These aerosol models are based almost entirely on surface and/or column averaged measurements and so may not accurately represent the ambient aerosol properties. Therefore, to validate these EOS algorithms, we have developed and are using the aerosol backscattering and extinction profiles measured by the CART Raman Lidar (CARL) to determine how the aerosol properties over the SGP site vary with altitude and time. Additional activities involve the use of the aerosol profiles measured by the GSFC Scanning Raman Lidar (SRL) during periodic field experiments to perform similar assessments. We have begun using these lidar aerosol and water vapor measurements for directly validating these Terra instruments.

SGP CART Raman Lidar (CARL) Instrument Status:

- During July 2000, CARL was down to repair high voltage air conditioning unit and the picomotors that control laser alignment.
- During January 2001, CARL was down for major laser maintenance.
- Between January 1998 through June 2001, CART Raman Lidar operated an average of 53% of the time. Since January 2000, system uptime has improved to nearly 66% of the time with several months having greater than 90% uptime. (**Figure 1**).

FY01 (Previous Year) Objectives

- We shall continue with routine processing of CART Raman lidar data and will monitor production of aerosol, water vapor, and best estimate products by ARM Experiment Center.
- We shall continue to evaluate CART Raman lidar aerosol extinction and optical thickness algorithms and retrievals with comparisons with Cimel Sun photometer data and other sensors. We shall extend our analyses of aerosol and water vapor vertical variability and relationship to relate humidity with the data collected on an ongoing basis.
- We shall continue acquiring MODIS data on a regular basis. We shall compare MODIS retrievals of aerosol optical thickness (AOT) and precipitable water vapor (PWV) with those derived from ARM SGP Raman lidar (AOT, PWV) and microwave radiometer (PWV). We shall also evaluate how the MODIS retrievals of aerosol Angstrom exponent compare with the CARL retrievals of the aerosol extinction/backscatter ratio.
- We shall begin acquisition of MISR aerosol level 2 data as they become available from the Langley DAAC. We shall compare MISR retrievals of aerosol optical thickness (AOT) with those derived from ARM SGP Raman lidar.
- We shall also begin to characterize the vertical distribution of aerosol extinction and water vapor over the SGP site during the MODIS and MISR retrievals.
- The SRL will be deployed to the ARM SGP Site to acquire high resolution measurements of water vapor and aerosols as part of the ARM/FIRE Water Vapor IOP Experiment (AFWEX). (This deployment is funded by the DOE.) The high resolution SRL measurements of aerosols and water vapor will be used to directly assess the measurements of MODIS and MISR as well as to assess the low altitude measurement capability of the upward-looking CART Raman lidar.
- Newly implemented aerosol Value Added Procedures (VAPs) using data from the DOE CART Raman lidar, which are a part of the automated data stream generated at the northern Oklahoma CART site, will be tested

using scanned data from the SRL. Assumptions about the vertical distribution of aerosols are made in these routines which can be tested using the data acquired by the SRL.

Data Processing Progress/Status:

- The series of Value Added Procedures (VAPs), which we developed for using the CART Raman lidar data to characterize the clear-sky state over the SGP site, have continued to be run at the Dept. of Energy Atmospheric Radiation Measurement (ARM) Experiment Center and periodically at NASA Langley Research Center. The output products from these VAPs included a series of netCDF files that include the profile results as well as several quick look GIF images to show the results of this processing. These VAPS include:
  - MR VAP (water vapor mixing ratio and relative humidity profiles)
  - ASR VAP (aerosol scattering ratio and backscatter coefficient profiles)
  - EXT VAP (aerosol extinction coefficient and extinction/backscatter ratio)
  - DEP VAP (depolarization and cloud mask profiles).
- The "best estimate" (BE) VAP, which combines the aerosol and water vapor profiles (Raman lidar) and temperature profiles (AERI+GOES) in order to characterize the clear sky atmospheric state above the CART site, has also continued to be run at the ARM Experiment Center and periodically at NASA Langley Research Center. The characteristics of these products are listed in **Table 1.** (These algorithms are described in a manuscript accepted by J. Atmos. Oceanic Tech. "Automated Retrievals of Water Vapor and Aerosol Profiles over Oklahoma from an Operational Raman Lidar", D.D. Turner, R.A. Ferrare, L.A. Heilman, W.F. Feltz, and T. Tooman).
- The "best estimate" data have been processed and are available in netCDF form by contacting either Ferrare or Turner or are available from the ARM experiment center. A web site showing these results for the periods listed above has been established at http://playground.arm.gov/~turner/raman_lidar_quicklooks.html**. Figure 2** shows examples of these images for a single day (December 3, 1998).
- We are presently acquiring MODIS level 2 products 04, 05, 06, and 07 as they are processed on the NASA GSFC Windhoek processing computer. We have developed software for subsetting these data and have been working with NASA GSFC personnel in adapting other GSFC MODIS software to run on Sun Workstations. We have begun analyzing these data and comparing MODIS results with ARM SGP measurements.
- We are also presently acquiring MISR level 2 products from the NASA Langley Atmospheric Sciences Data Center and are in the process of developing other software for displaying and subsetting these data sets.

Science Results

Water Vapor and Aerosol Optical Thickness Evaluations

- We have begun comparing the CARL water vapor and aerosol measurements with measurements made by in situ instruments on a small aircraft flown periodically (2-3 times/week) over the SGP site. These aircraft measurements are made as part of the In situ Aerosol Profiling (IAP) program developed by NOAA Climate Monitoring and Diagnostics Lab (CMDL) for the ARM program. Preliminary comparisons show relative humidity measurements derived from the CARL water vapor and AERI+GOES temperature data compare well with the corresponding IAP measurements (**Figure 3a**). Preliminary comparisons of aerosol extinction (550 nm) extrapolated from Raman lidar measurements at 355 nm and derived from IAP nephelometer scattering and Particle Soot Absorption Photometer (PSAP) show that the IAP measurements of aerosol extinction are about 30% below the CARL measurements (**Figure 3b**). The reasons for these differences are not presently known but may be related to the methods used to convert the IAP measurements from low to ambient relative humidities, corrections for supermicron scattering, and absorption. Comparisons of aerosol optical thickness (AOT) between CARL and the SGP Cimel Sun photometer have shown bias differences less than about 5%.

Vertical Variability of Aerosols and Water Vapor

- The Raman lidar aerosol extinction, water vapor, and relative humidity profiles have been used to examine the vertical variability of aerosols and water vapor. **Figure 4a** shows the average aerosol extinction profiles for various ranges of AOT for two years of data acquired between April 1998 though April 2000. The solid points

on this graph indicate the scale height of the aerosols. **Figure 4b** shows the same for water vapor mixing ratio. The aerosol scale height was between 1.0-1.2 km during the winter but rose to nearly 2 km in the summer. This behavior is in contrast to the scale height for water vapor mixing ratio, which remained nearly the same (2.0-2.5 km) during winter and summer. (Manuscript submitted to GRL: "Average Aerosol Extinction and Water Vapor Profiles Over the Southern Great Plains", D.D. Turner, R.A. Ferrare, L.A. Brasseur).

- We examined the aerosol extinction/backscattering (S_a) profiles derived from the CARL measurements to determine the how often aerosol optical and physical characteristics vary with relative humidity, aerosol depolarization, and aerosol optical thickness (**Figure 5**). Using data collected during 1998 and 199, we have found a slight increase in the aerosol extinction/backscatter ratio with relative humidity, consistent with that modeled by Ackermann (1998) for "continental" aerosols. These measurements also found that S_a was generally 5-10 sr higher during high AOT conditions consistent with uptake of water by hygroscopic aerosols. The CARL measurements also found S_a decreased with increasing depolarization. This trend does not suggest that large values of Sa are necessarily associated with high depolarization associated with nonspherical particles. The lack of an apparent enhancement in Sa with increasing depolarization may be because the effective particle sizes were smaller than the critical size needed for nonspherical effects to impact S_a. When CARL measured low Sa and high depolarization, the aerosols may have been associated with the rapid transport of soil dust from the west. Back trajectories indicated a trend for higher values of S_a for air masses that originated to the east and southeast of Oklahoma, which is consistent with previous observations of high Sa associated with air masses from urban/industrial areas (**Figure 6**). (Manuscript in press, "Raman Lidar Measurements of the Aerosol Extinction-to-Backscatter Ratio Over the Southern Great Plains", Ferrare, Turner, Brasseur, Feltz, Dubovik, Tooman).

MODIS Product Validation

- We have been acquiring MODIS level 2 products 04, 05, 06, and 07 since day 57 (Feb 26, 2000) from the NASA GSFC Windhoek computer and from the GSFC Distributed Active Archive Center (DAAC). We have begun comparisons of corrected optical depth land (MOD04), water vapor (IR), and water vapor (near IR) (MOD05) and the corresponding measurements from the ARM SGP sensors. We use Cimel Sun photometer, MFRSR, and Raman lidar AOT data within +/-45 minutes of the MODIS overpass. For acquiring data over the SGP site, these overpasses occur between 16:00-19:00 UT (10:00-13:00 CST) for daytime measurements. The Cimel and MFRSR AOT data are interpolated on wavelength to the MODIS wavelengths of 470 and 660 nm. The Raman lidar AOT at 355 nm is extrapolated to 470 nm using the AOT wavelength dependence from the MODIS measurements. The MODIS AOT data within a 25 km radius circle around the SGP site are averaged together to give a single value that we compare with the SGP measurements. **Figure 7** shows the results of comparisons between MOD04 and SGP measurements of AOT. The MOD04 AOT at 470 nm is slightly higher than the SGP measurements, especially at low AOT. Agreement is better at 670 nm where the majority of points lie within the predicted uncertainty of the MODIS AOT retrievals.
- **Figure 8** shows the results of comparisons between MOD05 near-IR and SGP measurements of PWV. The MOD05 near-IR PWV is about 30-40% higher than expected. This may be due to errors in the water vapor line parameters compiled in HITRAN96. HITRAN96-COR increased the 940 nm water vapor band intensity by 14.4%. However, when HITRAN96-COR was used to simulate AVIRIS spectra at 10 nm resolution, the shapes of the fitted spectra still did not agree with AVIRIS measurements, which indicates that the distributions of water vapor line intensities are still not correct. More recent lab measurements by Belmiloud et al. (GRL, Nov. 2000) suggest that the integrated 940 nm water vapor band intensity in HITRAN96 should be increased by 21.3%.
- **Figure 9** shows results comparisons between MOD07 IR and SGP measurements of PWV. These comparisons use the revised MOD07 IR retrieval algorithm that was implemented late in 2000. The MOD07 IR PWV also tends to be biased slightly high. Possible explanations are a bias between the pre-launch and in-orbit wavelength responses of 6.7 mm MODIS channel, and an incorrect specification of surface pressure in operational retrievals. Updated algorithms are currently nearing completion and implementation.

Comparison of GSFC Scanning Raman Lidar (SRL) measurements and GOES

- Published paper ("Raman lidar measurements of water vapor and cirrus clouds during the passage of hurricane Bonnie Whiteman", D. N., K. D. Evans, B. Demoz, D. O'C. Starr, D. Tobin, W. Feltz, G. J. Jedlovec, S. I.

Gutman, G. K. Schwemmer, M. Cadirola, S. H. Melfi, F. J. Schmidlin, 2001:, *J. of Geophys. Res.*, 106, No. D6, 5211-5225). Conclusion of this paper is that GOES retrievals of PW can be high-biased by ~20 over land and ~40% over water due to undetected cirrus clouds.

GSFC SRL measurements of water vapor and clouds

- The GSFC SRL system participated in the Water Vapor IOP 2000 (Sept. 2000) and ARM/FIRE Water Vapor Experiments (Dec. 2000) held at the ARM SGP site. The SRL was used to measure water vapor and cirrus clouds in the upper troposphere (**Figure 10**). SRL data have also been used to derive cirrus cloud optical depths and to evaluate the cirrus cloud optical depths derived from the CARL measurements using two different techniques (**Figure 11**). Of the two CARL routines, the direct attenuation procedure retrieves optical depth for a larger portion of the cirrus cloud although the scatter in the points is considerably larger for the CARL instrument due to the lower signal strengths of the data. Note that CARL's signal strength at cirrus altitudes is about a factor of 20 less than that of the Scanning Raman Lidar.
- SRL water vapor measurements acquired during WVIOP2000 have also begun to be used to evaluate the MODIS IR water vapor measurements (**Figure 12**). Initial comparisons indicate that the MODIS IR water vapor product underestimates the PWV value as PWV increases. The comparison of the SRL and CART MWR PWV measurements indicate no discernable trends with increasing water vapor burden.

Collaborations

- Have been in extensive contact with MODIS atmospheres team (Yoram Kaufman, Lorraine Remer) regarding use of CART Raman lidar data for characterizing vertical distribution of aerosols
- Have been working with Bill Ridgway and Eric Moody (NASA GSFC) in acquiring MODIS data products and in producing a subset of these products over the ARM SGP site.
- As chair of the DOE ARM Aerosol Working Group, Ferrare is helping to coordinate efforts between NASA EOS Validation and the DOE ARM Aerosol Working Group. A proposal to hold an Aerosol IOP at the DOE ARM SGP site was recently submitted to the DOE Chief Scientist and Technical Manager.
- Have been in extensive contact with members of the NASA ESSP3 (formerly PICASSO-CENA) team in their efforts to develop algorithms for retrieving aerosol backscattering and extinction profiles from the ESSP3 satellite sensor to be launched in 2004. Ferrare chaired a preliminary ESSP3 algorithm review panel.
- Have been collaborating with Elizabeth Andrews (Cooperative Institute for Research in Environmental Sciences, University of Colorado) and John Ogren (NOAA/Climate Monitoring and Diagnostics Laboratory) in analyses of In situ Aerosol Profiling (IAP) measurements over the ARM SGP site.

Data archival and access

- "Best estimate" data have been processed and are available in netCDF form by contacting either Ferrare or Turner. These data cover the periods: September 1996 (Water Vapor IOP #1), September-October 1997 (Water Vapor IOP#2, Aerosol IOP), and April 1998 through the present (July 2001). A web site showing these results for the periods listed above has been established at http://playground.arm.gov/~turner/raman_lidar_quicklooks.html . These files are also available from the ARM archive (http://www.archive.arm.gov/data/ordering.html) where they will be available for public access. Best estimate products are being produced on a routine basis by automated software at the DOE ARM Experiment Center. These data are also available from the ARM Archive.

Web pages

Main validation web page: http://dev.www.ec.arm.gov/~turner/EOS_validation/
"Best-estimate" quicklook images: http://playground.arm.gov/~turner/raman_lidar_quicklooks.html
Related URLs: http://playground.arm.gov/~turner/doe_aerosols.html
http://r1.sgp.arm.gov/~dturner/quicklooks/

FY02 Planned Activities (6-month extension)

CART Raman Lidar data processing

- We shall continue to monitor production of aerosol, water vapor, and best estimate products by ARM Experiment Center.
- We shall continue to evaluate CART Raman lidar aerosol extinction and optical thickness algorithms and retrievals with comparisons with Cimel Sun photometer data, In Situ Aircraft Profiling (IAP) data, and other sensors.

MODIS and MISR data evaluation

- We shall continue acquiring MODIS data on a regular basis. We shall compare MODIS retrievals of aerosol optical thickness (AOT) and precipitable water vapor (PWV) with those derived from ARM SGP Raman lidar (AOT, PWV) and microwave radiometer (PWV). We shall also evaluate how the MODIS retrievals of aerosol Angstrom exponent compare with the CARL retrievals of the aerosol extinction/backscatter ratio.
- We shall continue acquiring MISR aerosol level 2 data as they become available from the Langley DAAC. We shall compare MISR retrievals of aerosol optical thickness (AOT) with those derived from ARM instruments as well as with MODIS when possible.
- We shall also continue to characterize the vertical distribution of aerosol extinction and water vapor over the SGP site during the MODIS and MISR retrievals.

NASA/GSFC Scanning Raman Lidar (SRL)

- Aerosol data acquired during the WVIOP2000 will be analyzed so that comparisons of SRL and CARL extinction retrievals in the boundary layer can be performed. This will address potential error sources in the CARL retrievals that may be influencing comparisons with EOS sensors.

Presentations

"Research Efforts in the Absolute Calibration of a Raman Water Vapor Lidar", D.N. Whiteman, T. Berkoff, D.D. Turner, T. Tooman, R.A. Ferrare, L.A. Heilman, 20th International Laser Radar Conference, Vichy, France, July 10-14, 2000.

"Raman lidar and IAP Aerosol Measurements", R. Ferrare, L.H. Heilman, D. Turner, J. Ogren, B. Andrews, IAP Program Review, Richland, WA, January 10, 2001.

"Evaluation of Terra MODIS Aerosol and Water Vapor Measurements Using ARM SGP Data", R. Ferrare, L. H. Brasseur, D. Turner, MODIS Atmospheres Group Meeting, NASA Goddard Space Flight Center, January 23, 2001.

"Evaluation of Terra MODIS Aerosol and Water Vapor Measurements using ARM SGP Data", Ferrare, R. A. Ferrare, Brasseur, L. H., Turner, D. D., Tooman, T. P.(e), Remer, L., and Gao, B-C., 11th ARM Science Team Meeting, Atlanta, Georgia, March 19-23, 2001.

"Raman Lidar Characterization of the Vertical Variability of Aerosols and Water Vapor over the SGP", R.A. Ferrare, D.D. Turner, L.A. Heilman, Tim Tooman, O. Dubovik, J.E.M. Goldsmith, J.A. Ogren, W. F. Feltz, 11th ARM Science Team Meeting, Atlanta, Georgia, March 19-23, 2001.

"Raman lidar profiling of aerosols over the Southern Great Plains", R. Ferrare, D. Turner, L. H. Brasseur, T. Tooman, J.E.M. Goldsmith, O. Dubovik, J. A. Ogren, PICASSO-CENA Science Team Meeting, April 5, 2001, Hampton, VA

"Recent Progress in CART Raman Lidar Measurements", Goldsmith, J. E. M., Ferrare, R. A., Tooman, T. P., and Turner, D. D., 11th ARM Science Team Meeting, Atlanta, Georgia, March 19-23, 2001.

"Evaluation of Terra MODIS Aerosol and Water Vapor Measurements using ARM SGP Data". R.A. Ferrare, Lorraine Brasseur, Dave Turner, Tim Tooman, Lorraine Remer, Bo-Cai Gao, AGU Spring Meeting, Boston, MA May 31-June 3, 2001.

Publications

Kato, S., M.H. Bergin, T.P. Ackerman, T.P. Charlock, E.E. Clothiaux, R.A. Ferrare, R.N. Halthore, N. Laulainen, G.G. Mace, J. Michalsky, and D.D. Turner, A comparison of the aerosol optical thickness derived from ground-based and airborne measurements, *J. Geophys. Res.*, 105, No. D11, 14701-14717, 2000.

Peppler, R.A., C.P. Bahrmann, J.C. Barnard, J.R. Campbell, M.-D. Cheng, R.A. Ferrare, R.N. Halthore, L.A. Heilman, D.L. Hlavka, N.S. Laulainen, C.-J., Lin, J.A. Ogren, M.R. Poellot, L.A. Remer, K. Sassen, J.D. Spinhirne, M.E. Splitt, D.D. Turner, ARM Southern Great Plains Site Observations of the Smoke Pall Associated with the 1998 Central American Fires, *Bull. Amer. Meteor. Soc.*, 81, 2563-2592, 2000.

Turner, D.D., W.F. Feltz, and R.A. Ferrare, Continuous water vapor profiles from operational ground-based active and passive remote sensors, *Bull. Amer. Meteor. Soc.*, 81, 1301-1317, 2000.

Whiteman, D.N., G. Schwemmer, D. O'C. Starr, K.D. Evans, B. Demoz, T. Berkoff, S.H. Melfi, M. Cadirola, and G. Jedlovec, "The use of Raman Lidar in Cloud Studies", in Advances in Laser Remote Sensing, Selected Papers Presented at the 20th International Laser Radar Conference (ILRC), Vichy, France, 10-14 July 2000, A. Dabas, C. Loth, and J. Pelon, eds., Ecole polytechnique, France, pp. 271-274, 2001.

Turner, D.D., R.A. Ferrare, L.A. Heilman, T. T. Tooman, A Two Year Climatology of Water Vapor and Aerosols in the Lower Troposphere Measured by a Raman Lidar, in Advances in Laser Remote Sensing, Selected Papers Presented at the 20th International Laser Radar Conference (ILRC), Vichy, France, 10-14 July 2000, A. Dabas, C. Loth, and J. Pelon, eds., Ecole polytechnique, France, pp. 309-312, 2001.

Whiteman, D. N., K. D. Evans, B. Demoz, D. O'C. Starr, D. Tobin, W. Feltz, G. J. Jedlovec, S. I. Gutman, G. K. Schwemmer, M. Cadirola, S. H. Melfi, F. J. Schmidlin, 2001: Raman lidar measurements of water vapor and cirrus clouds during the passage of hurricane Bonnie, *J. of Geophys. Res.*, 106, No. D6, 5211-5225.

Ferrare, R.A., D.D. Turner, L.A. Heilman, O. Dubovik, and W. Feltz, Raman Lidar Measurements of the Aerosol Extinction-to-Backscatter Ratio Over the Southern Great Plains, J. Geophys. Res., in press, May, 2001.

Turner, D.D., R.A. Ferrare, L.A. Heilman, W.F. Feltz, and T. Tooman, Automated Retrievals of Water Vapor and Aerosol Profiles over Oklahoma from an Operational Raman Lidar, J. Appl. Meteor., in press, July 2001.

Andrews, E., J. Ogren, P. Sheridan, R.A. Ferrare, In Situ Aerosol Profiles over the Southern Great Plains CART site, in preparation , 2001.

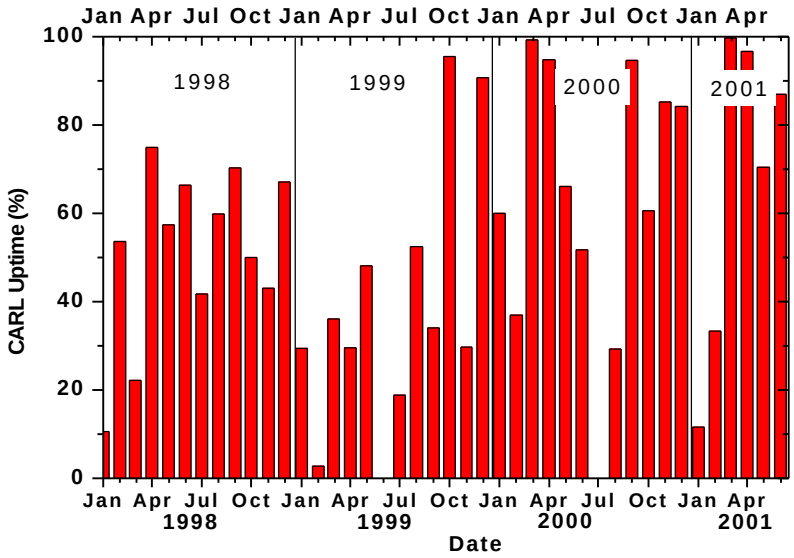


Figure 1. Percentage of run time for CART Raman lidar during each month from August 1997 to May 2000.

Table 1. CART Raman Lidar/AERI+Model Clear-Sky Product Parameters

Measurement	Altitude Range	Vertical Resolution	Nominal Temporal Resolution	Error	Precision	Detection Limit
Aerosol Backscattering (355 nm)	0.060-8 km	78 m	10 min	5-10%	2%	0.0002-0.0004 km-sr^{-1}
Aerosol Extinction (355 nm)	0.1-8 km	150-500 m	10 min	5-10%	5%	0.02-0.03 km^{-1}
Aerosol Optical Thickness (355 nm)	-	-	10 min	5% or 0.03	5%	0.03
Water Vapor Mixing Ratio	0.060-8 km (night) 0.060-4 km (day)	78 m	2-10 min	5%	2%	0.002 g/kg
Relative Humidity	0.060-8 km (night) 0.060-4 km (day)	78 m	2-10 min	5%	5%	1%
Precipitable Water Vapor	-	-	10 min	5%	5%	2 mm
Linear Depolarization	1-14 km	39 m	1-10 min	10%	2%	
Temperature (AERI+Model)	0-3 km (AERI) 3-15 (Model)	100 m - 1 km	8 min	1 K	1 K	
Cloud Base Height	0.060-14 km	78 m	1-10 min	78 m	39 m	0.060 km

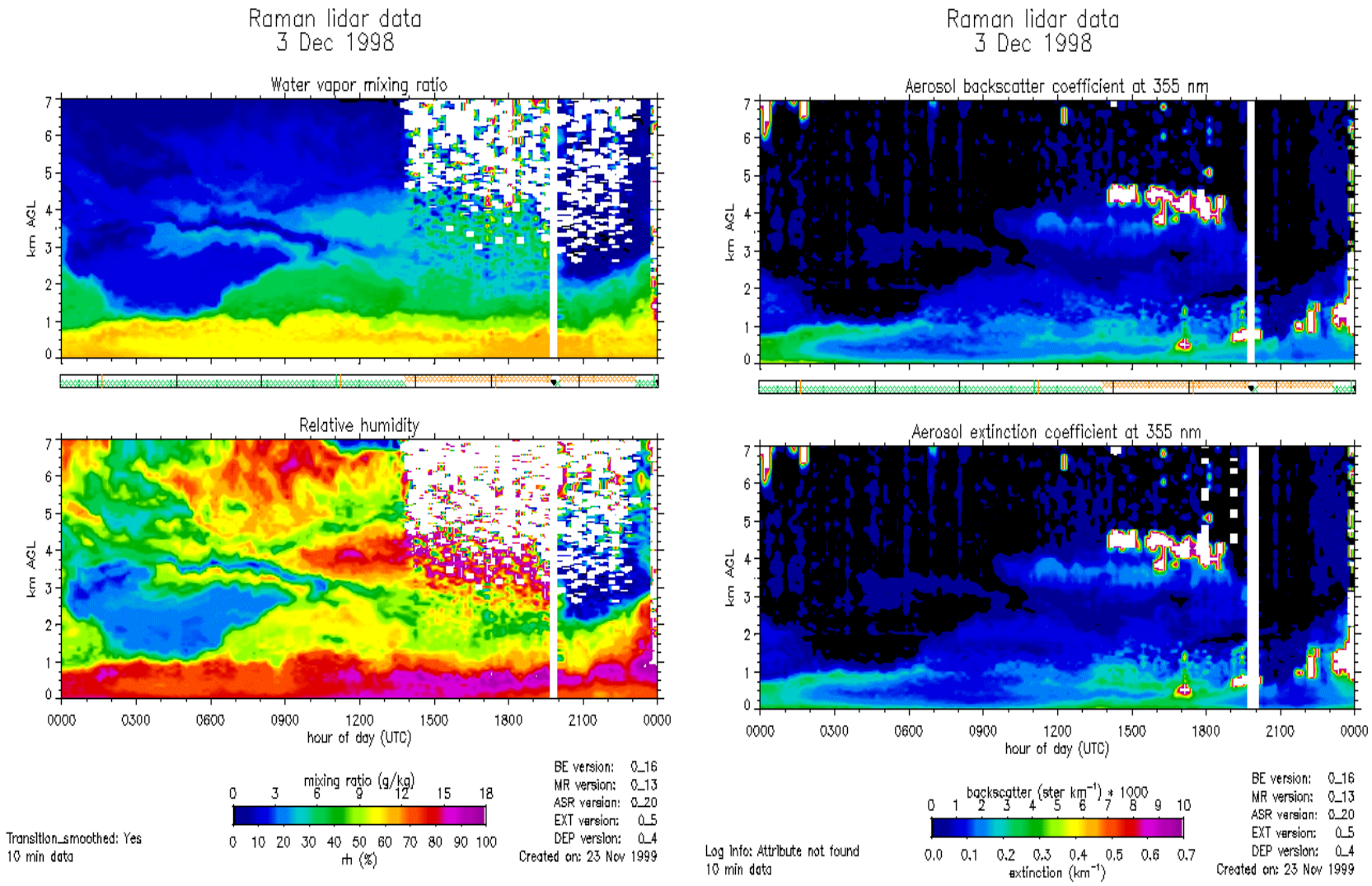


Figure 2. Example of CART Raman lidar water vapor (left) and aerosol (right) “quicklook” images for December 3, 1998.

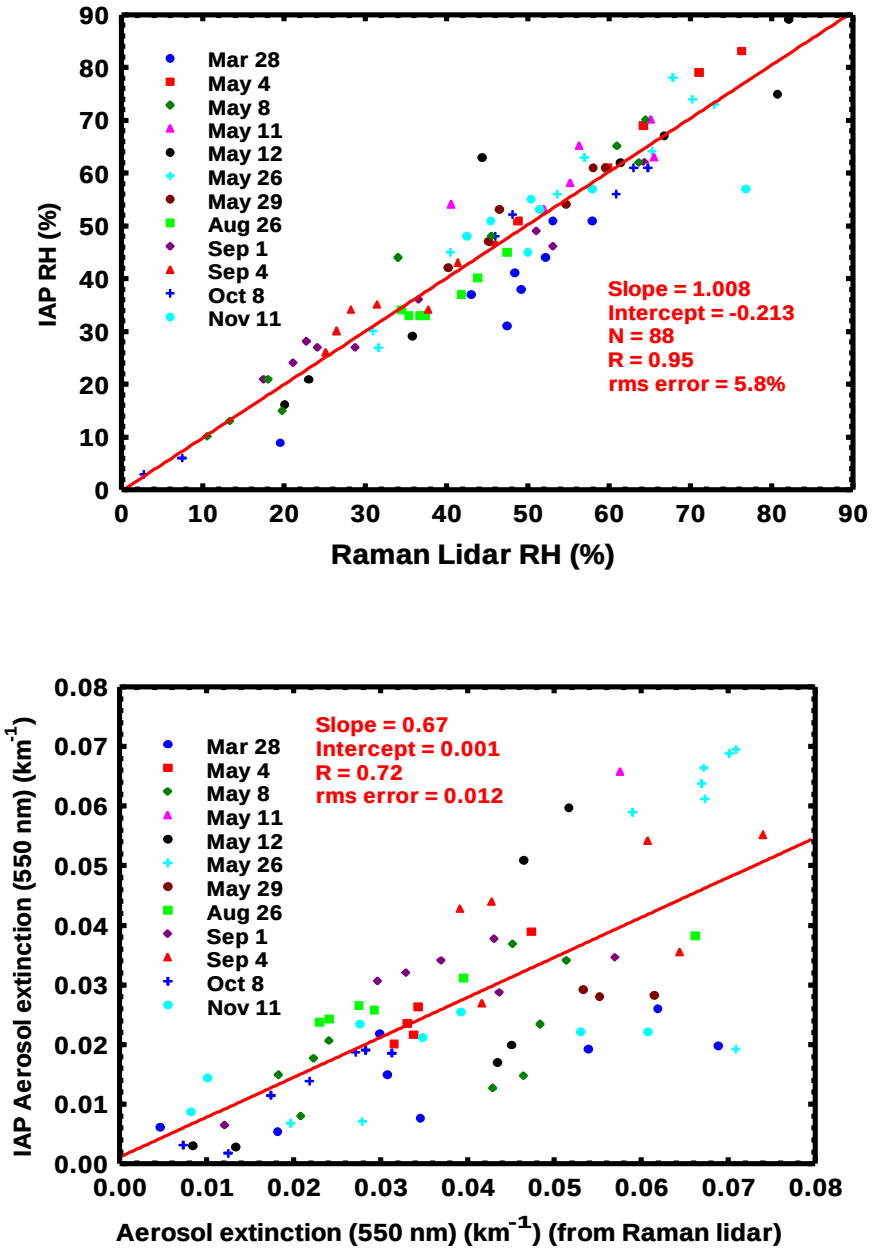


Figure 3a. (top) Comparison of RH derived from CARL and AERI+GOES measurements and from In situ Aerosol Profiling Measurements. 3b. (bottom) same except for aerosol extinction.

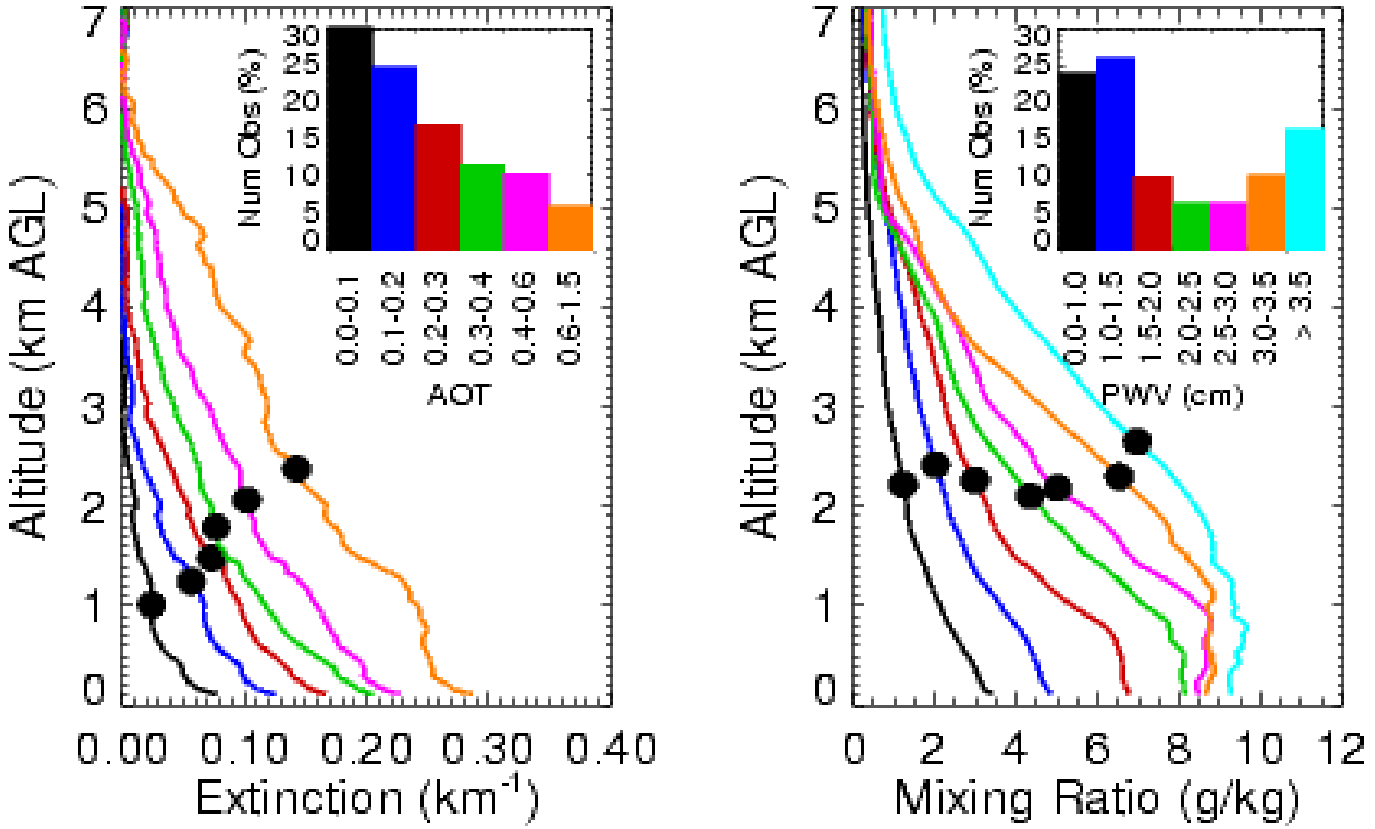
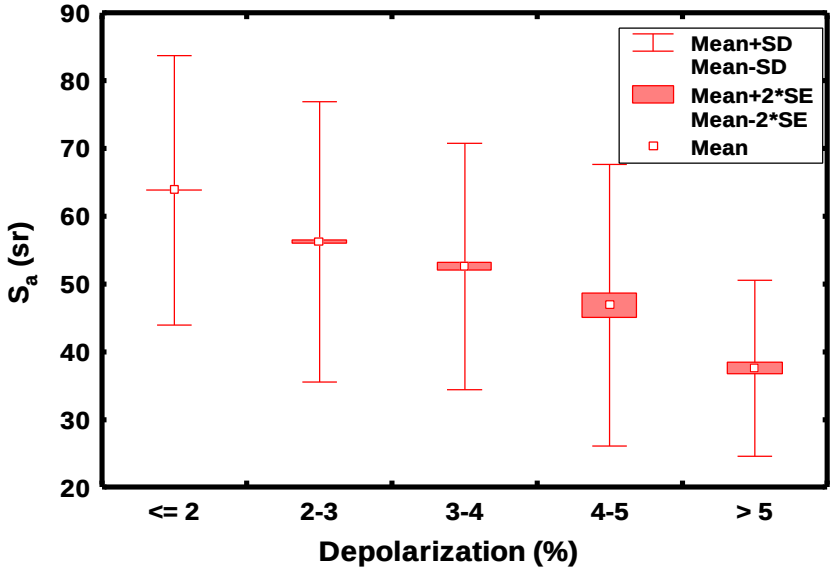
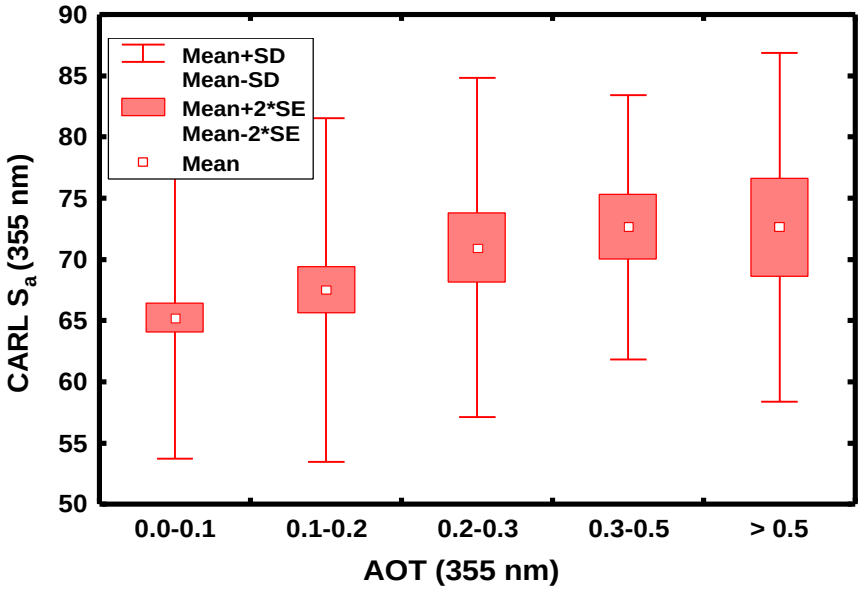
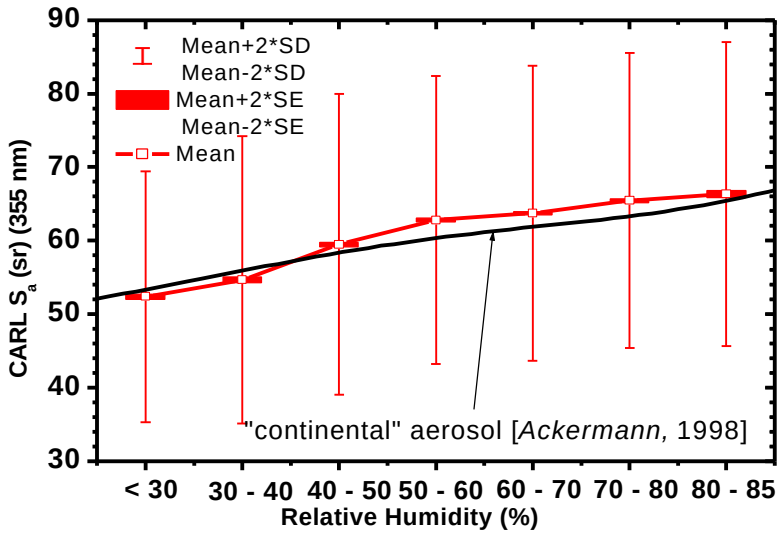


Figure 4a. (left) Mean aerosol extinction profiles computed from 2 years of data from the operational Raman lidar at the Atmospheric Radiation Measurement (ARM) site in the Southern Great Plains (SGP). 4b) (right) same except for water vapor mixing ratio. Mean profiles separated as a function of integrated amount -- aerosol optical thickness (AOT) or precipitable water vapor (PWV). Black dots indicate the scale height of the mean profiles. Note the significant change in the scale height as a function of AOT in the aerosol profiles, but that the scale height of the water vapor profiles is relatively unchanged.

Figure 5. Variation of the aerosol extinction/backscatter ratio (S_a) as functions of depolarization (top right), aerosol optical thickness (AOT) (bottom left), and relative humidity (bottom right) using CARL measurements acquired during 1998 and early 1999.







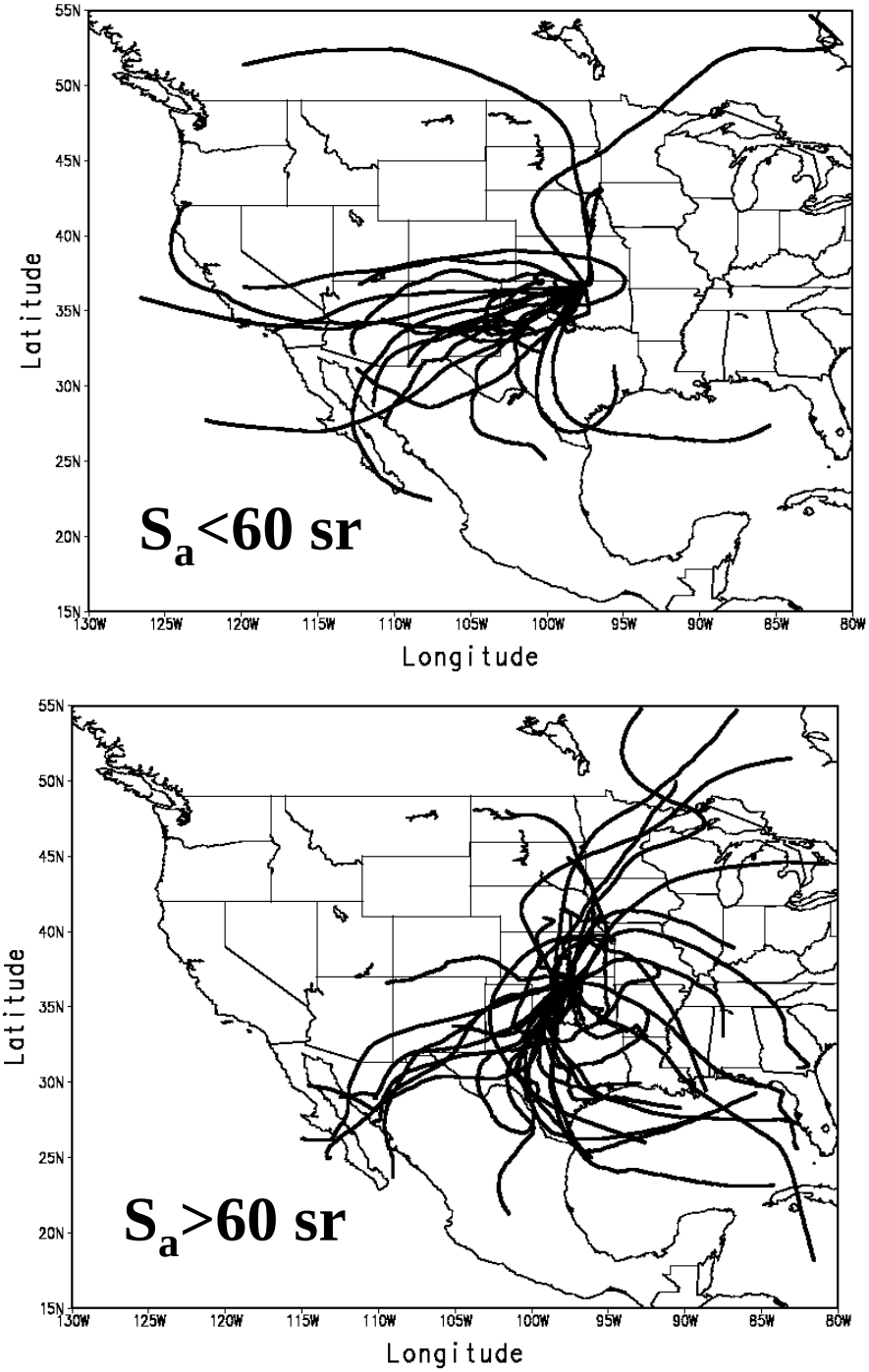


Figure 6a). (top) Three day back trajectories for air masses associated with CARL S_a values less than 60 sr. (bottom) same except for S_a values greater than 60 sr.

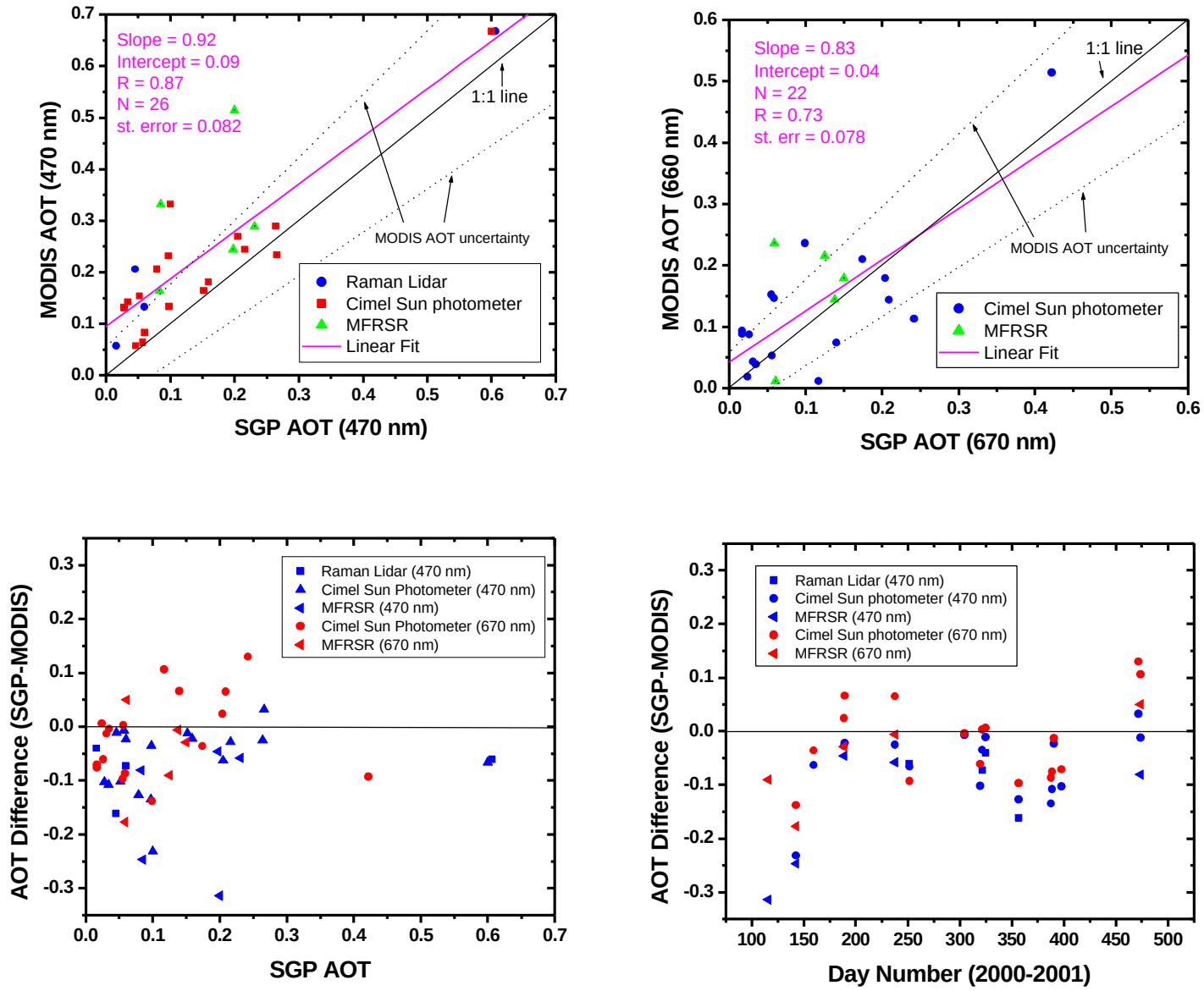


Figure 7. Comparisons between MOD04 and SGP measurements of AOT. The MOD04 AOT at 470 nm is slightly higher than the SGP measurements, especially at low AOT. Agreement is better at 670 nm where the majority of points lie within the predicted uncertainty of the MODIS AOT retrievals.

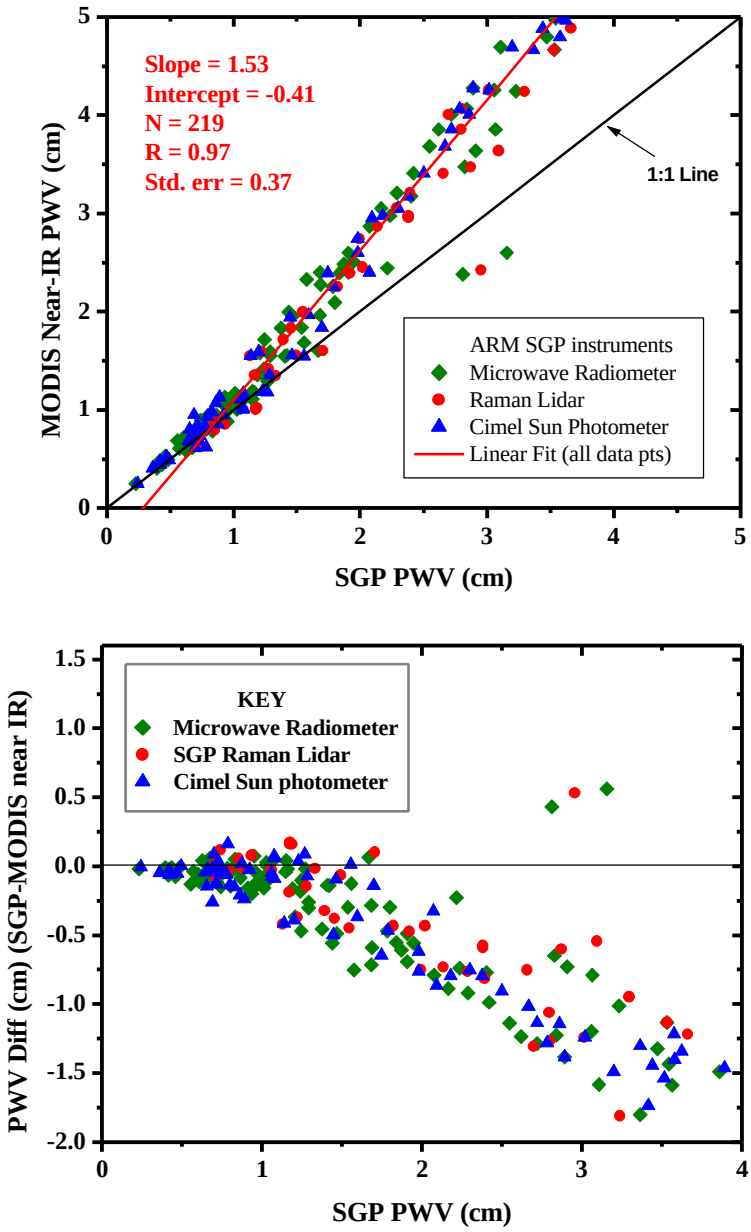


Figure 8. Comparisons between MOD05 near-IR and SGP measurements of PWV. The MOD05 near-IR PWV is about 30-40% higher than expected. This may be due to errors in the water vapor line parameters compiled in HITRAN96. HITRAN96-COR increased the 940 nm water vapor band intensity by 14.4%. However, when HITRAN96-COR was used to simulate AVIRIS spectra at 10 nm resolution, the shapes of the fitted spectra still did not agree with AVIRIS measurements, which indicates that the distributions of water vapor line intensities are still not correct. More recent lab measurements by Belmiloud et al. (GRL, Nov. 2000) suggest that the integrated 940 nm water vapor band intensity in HITRAN96 should be increased by 21.3%.

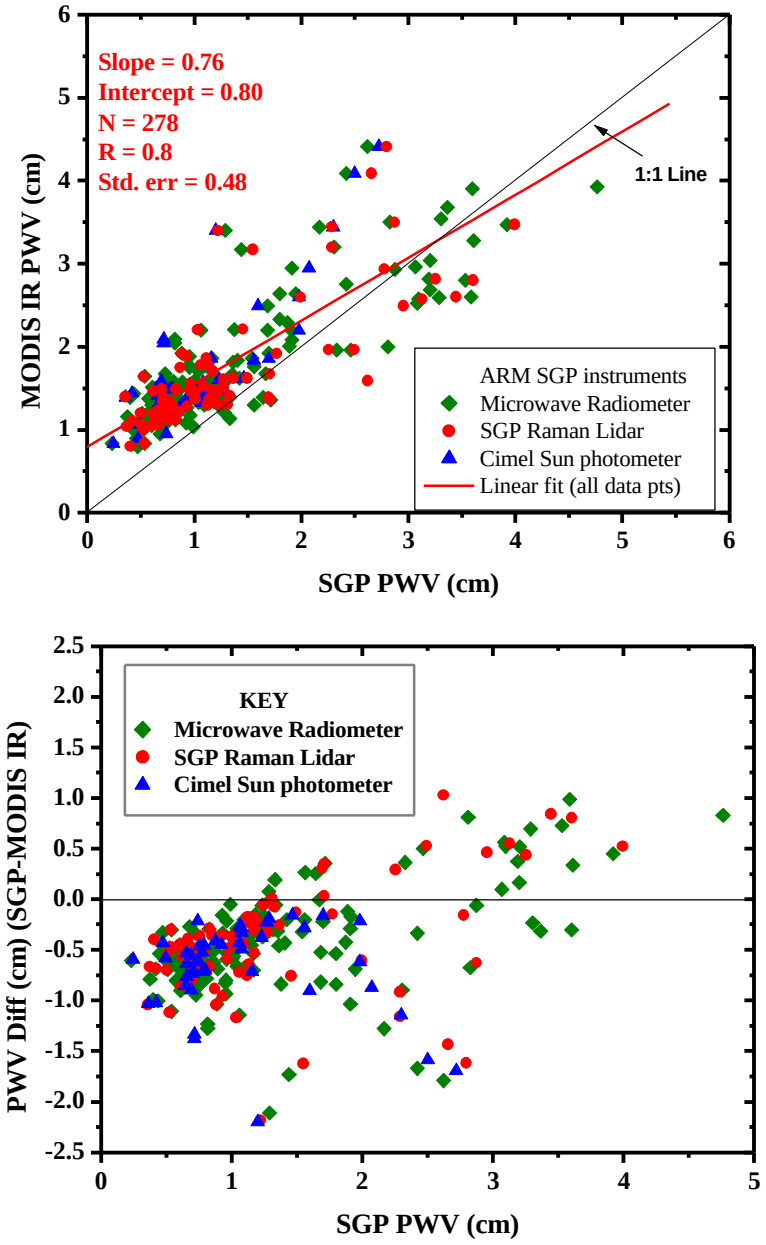


Figure 9. Comparisons between MOD07 IR and SGP measurements of PWV. These comparisons use the revised MOD07 IR retrieval algorithm that was implemented late in 2000. The MOD07 IR PWV also tends to be biased slightly high. Possible explanations are a bias between the pre-launch and in-orbit wavelength responses of 6.7 mm MODIS channel, and an incorrect specification of surface pressure in operational retrievals. Updated algorithms are currently nearing completion and implementation.

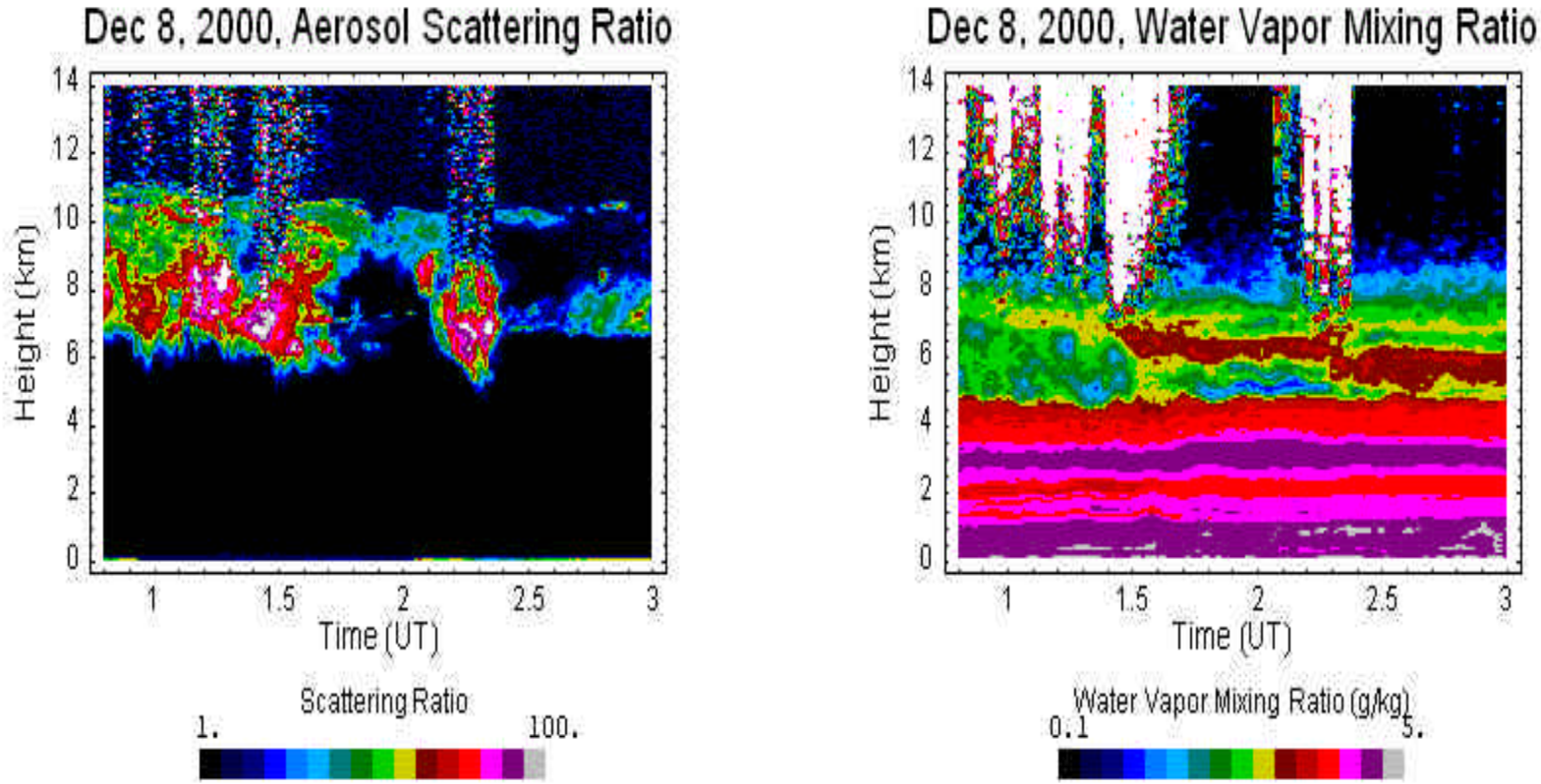


Figure 10. Aerosol Scattering Ratio (left) and Water Vapor Mixing Ratio (right) measured on the night of December 8, 2000 by the NASA GSFC Scanning Raman Lidar during the presence of cirrus clouds. Simultaneous optical depth measurements of the CART Raman Lidar and the SRL were possible (Figure 11).

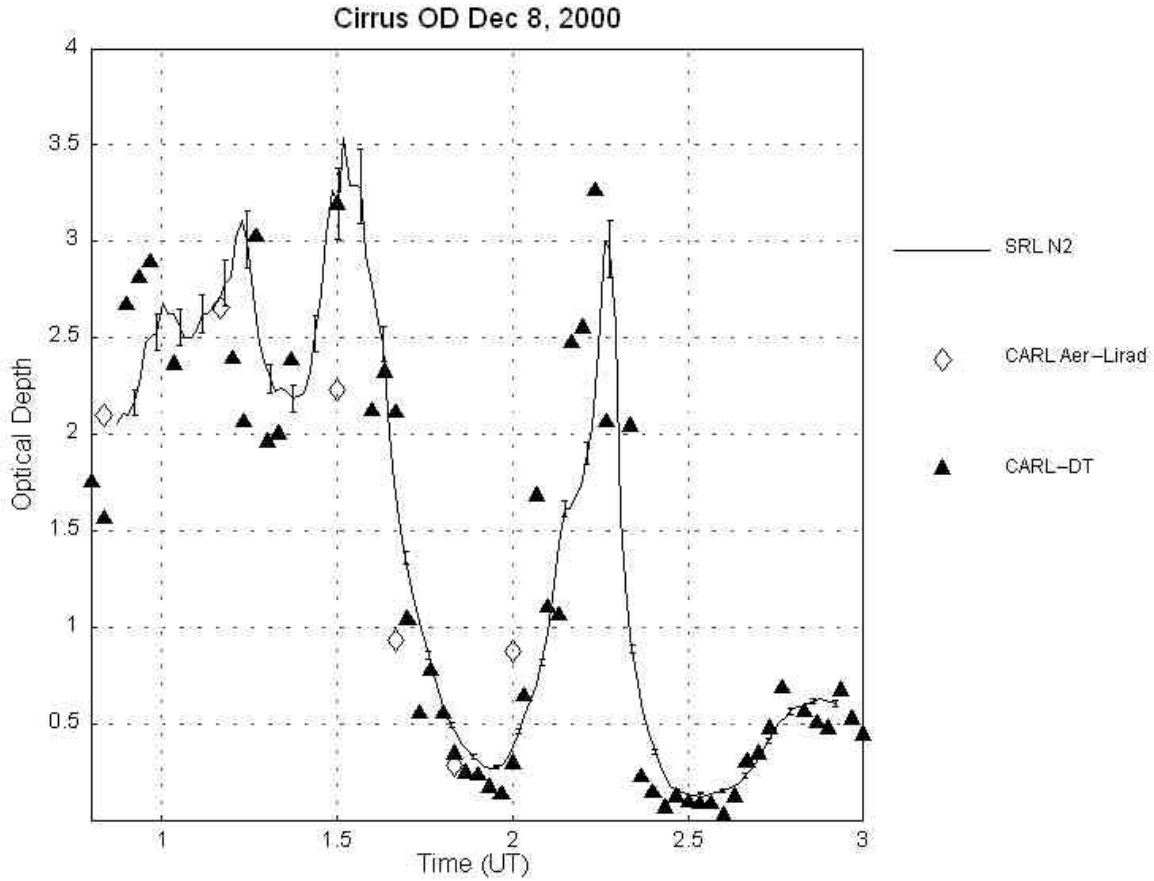
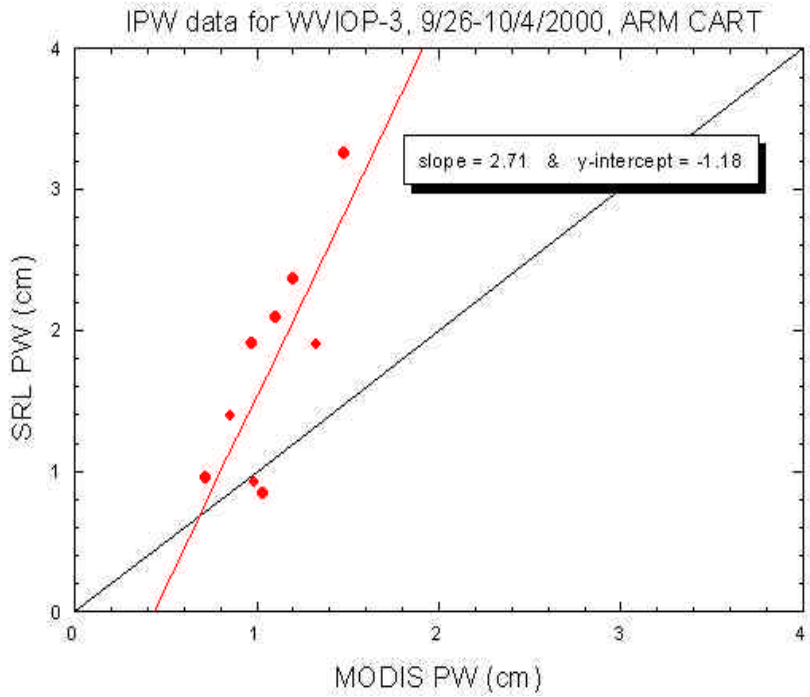


Figure 11. Comparison of SRL optical depths and those measured by CART Raman Lidar using two different retrievals: 1) a Lirad type technique 2) direct attenuation technique similar to that used in the SRL retrievals. Of the two CARL routines, the direct attenuation procedure retrieves optical depth for a larger portion of the cirrus cloud although the scatter in the points is considerably larger for the CARL instrument due to the lower signal strengths of the data.



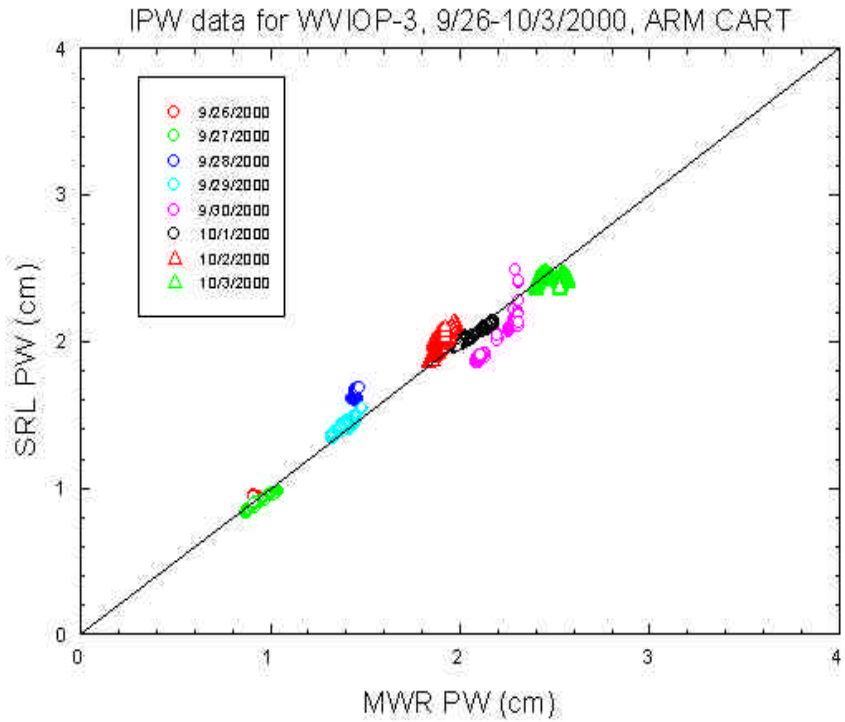


Figure 12. Comparisons of precipitable water vapor measured by NASA GSFC Scanning Raman Lidar and MODIS IR over the ARM SGP during Water Vapor IOP 2000. These nighttime comparisons show that for precipitable water measurements, MODIS increasingly underestimates the value as PW increases. The comparison of the SRL and CART MWR PW measurements are also shown indicating no discernable trends with increasing water vapor burden. The MWR was used as the source of the lidar calibration for the measurements reported here.